

# An SEP Event Model for WSA ENLIL

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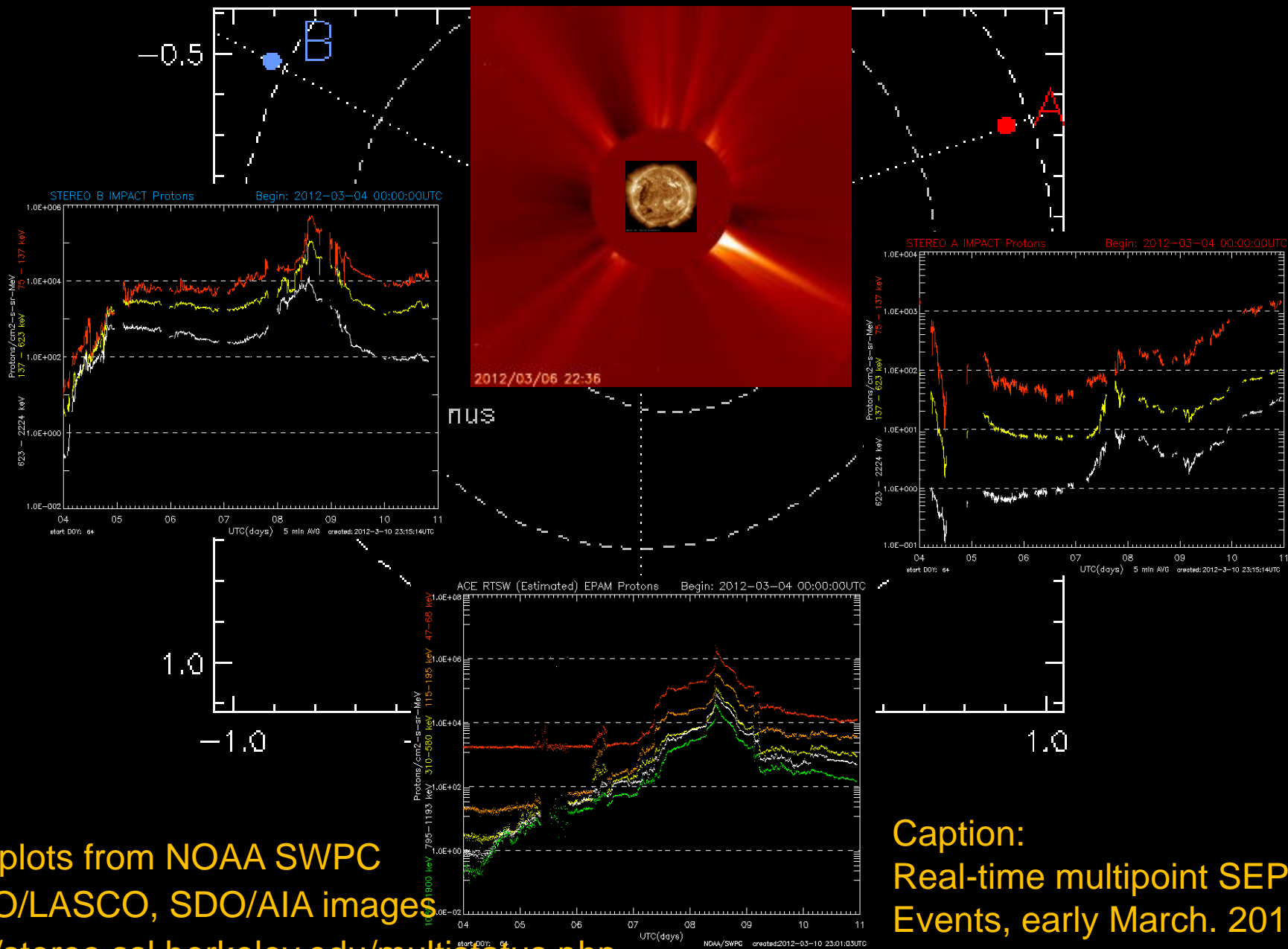
# The CISM SEP Model

- A test particle code that uses the time-dependent fields and shock information from MHD heliospheric CME/ICME simulations for **FORWARD MODELING** SEP event time profiles (\* can use any MHD model results)
- Approach:

A field-line tracer adapted for guiding-center particle trajectories of 10-100 MeV ions of any mass and charge is now modified to include energies down to 1 MeV. Energy-dependent scattering has been phenomenologically added that delays the lower energy particles' departure from the shock vicinity.

Uses an MHD shock parameter-based 'black box' source description that is the same for all events. An ESP enhancement with softer spectrum is assumed to travel with the shock.

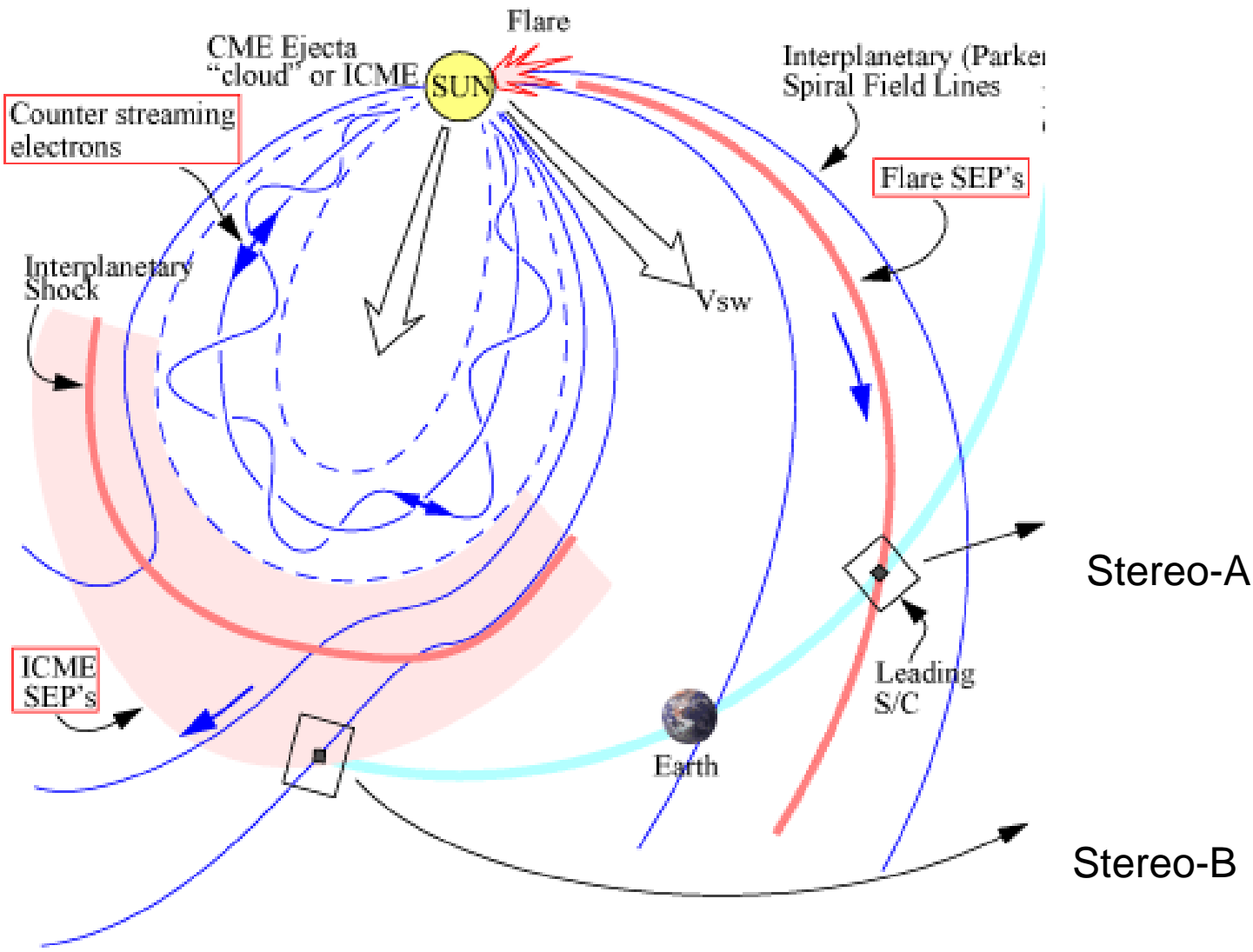
# now available: STEREO (and ACE) real-time multipoint perspectives at 1 AU



Caption:  
Real-time multipoint SEP  
Events, early March. 2012

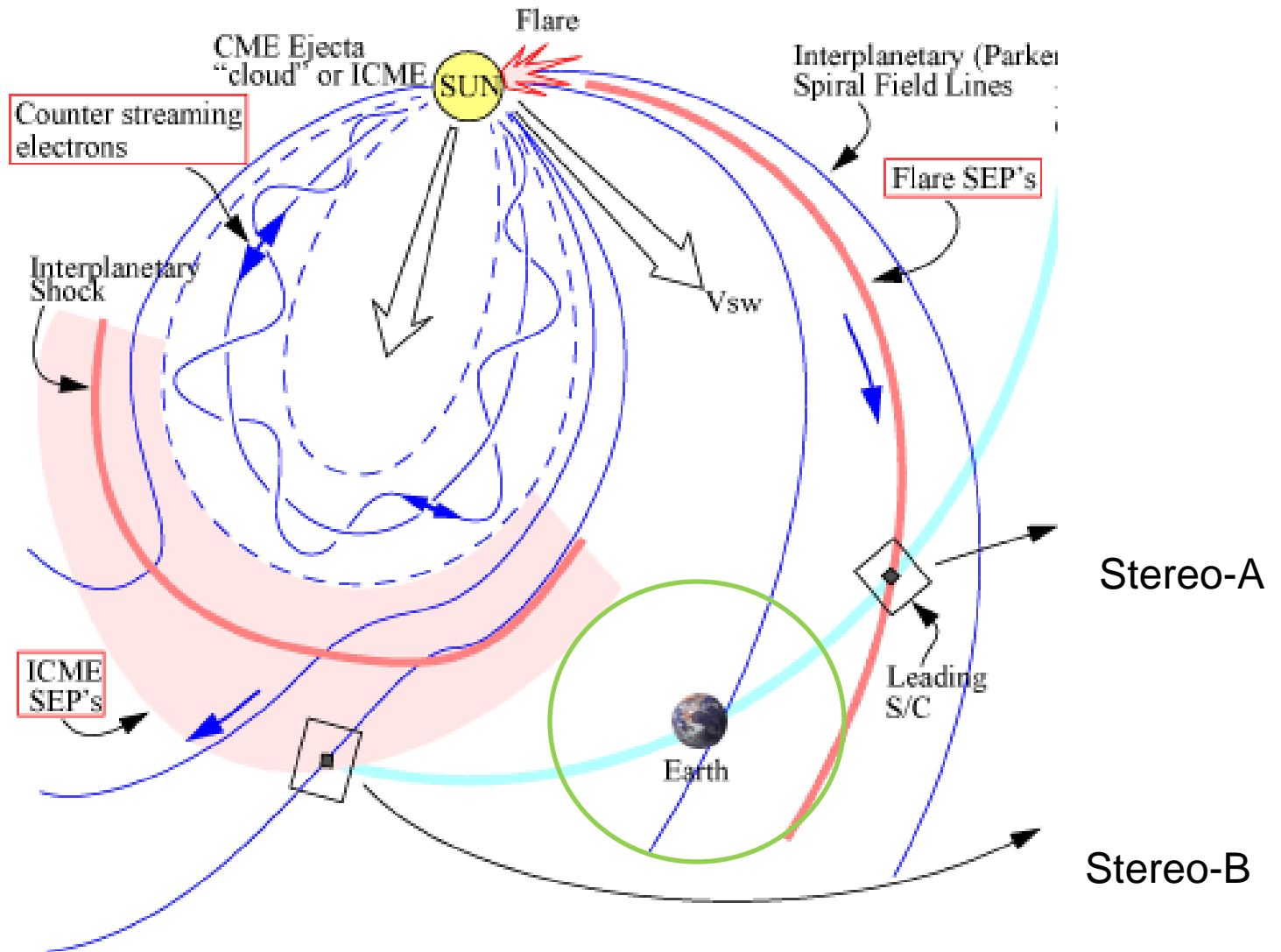
Data plots from NOAA SWPC  
SOHO/LASCO, SDO/AIA images  
<http://stereo.ssl.berkeley.edu/multistatus.php>

# Observer SEP experience depends on location relative to events



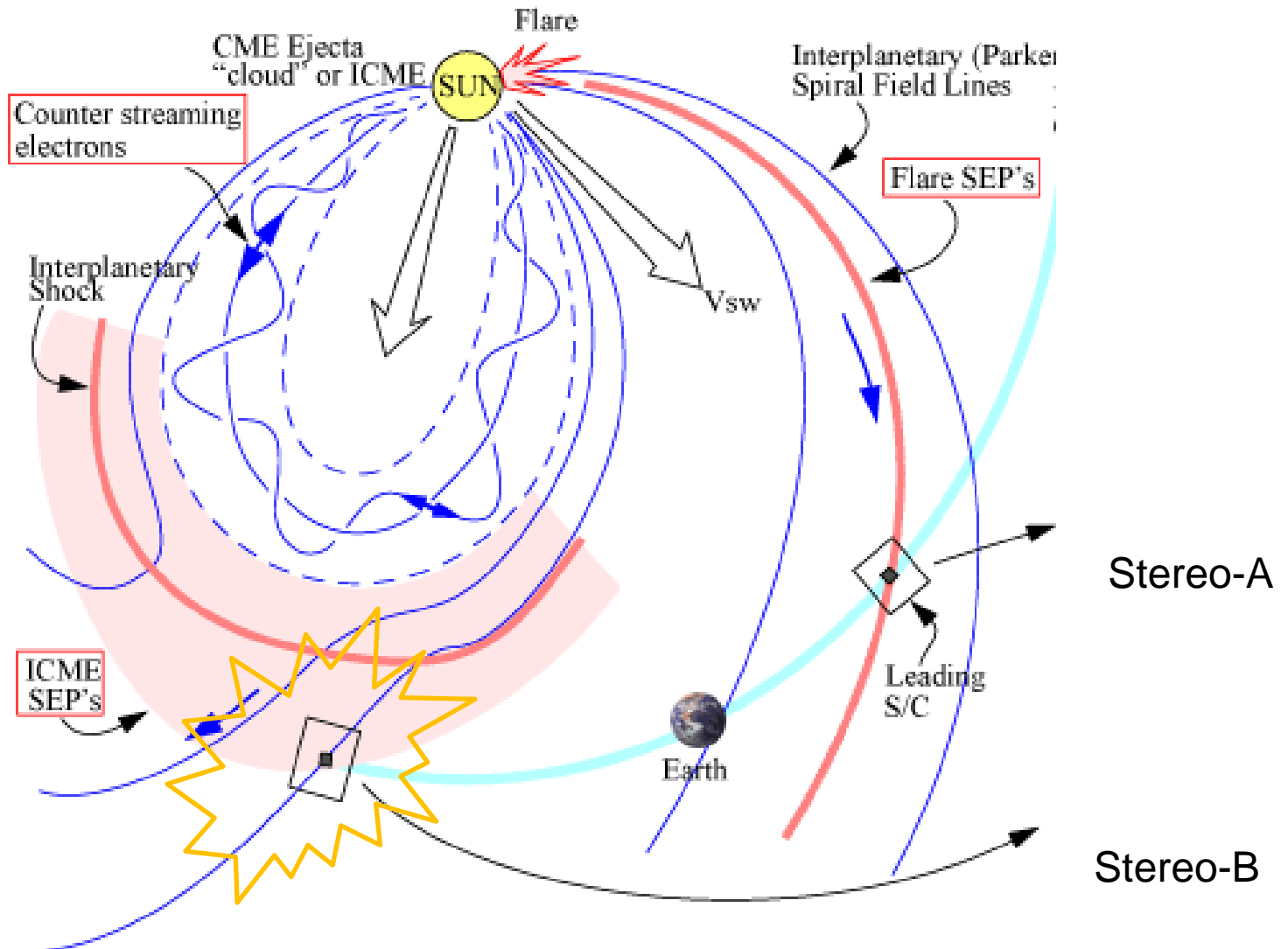


# Observer SEP experience depends on location relative to events



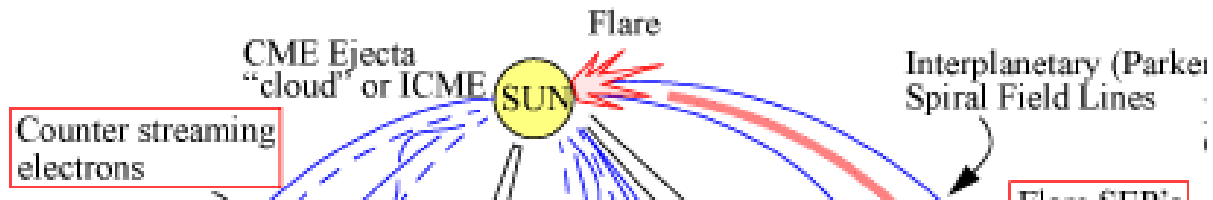
Near-Earth observer may see no SEPs

# Observer SEP experience depends on location relative to events

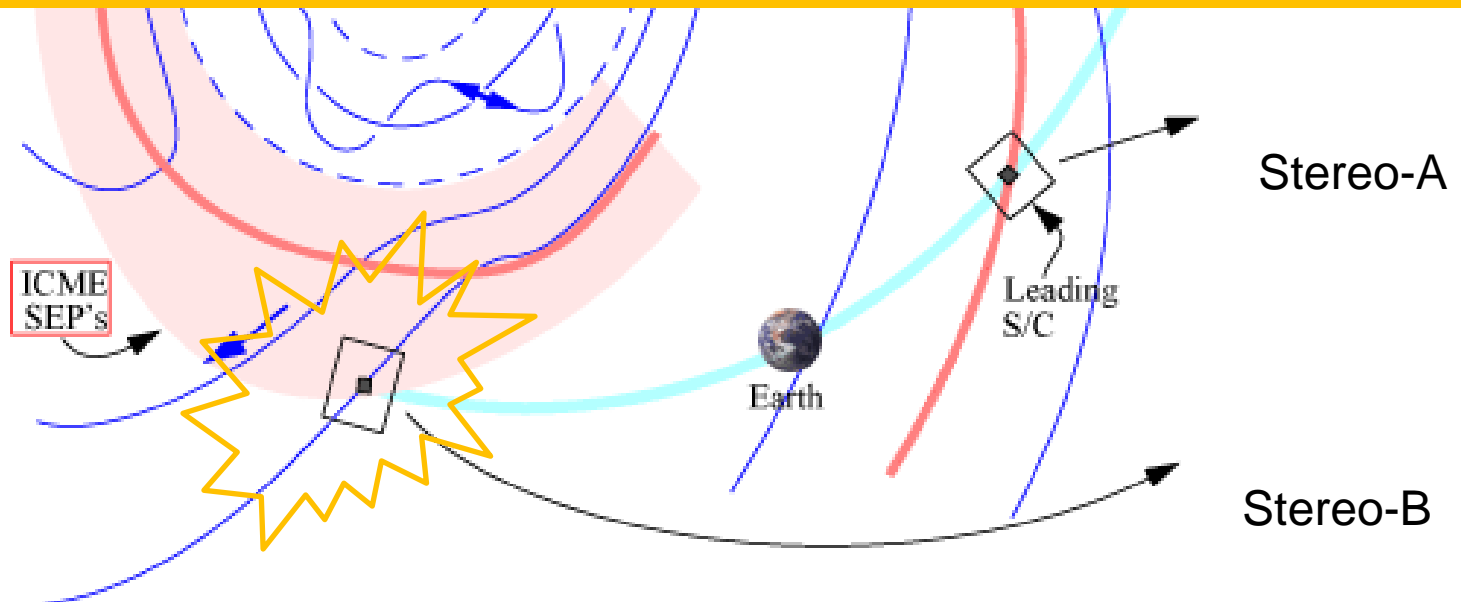


Stereo-B sees ICME and 'gradual' SEPs from its leading shock

Observer SEP experience depends on location relative to events



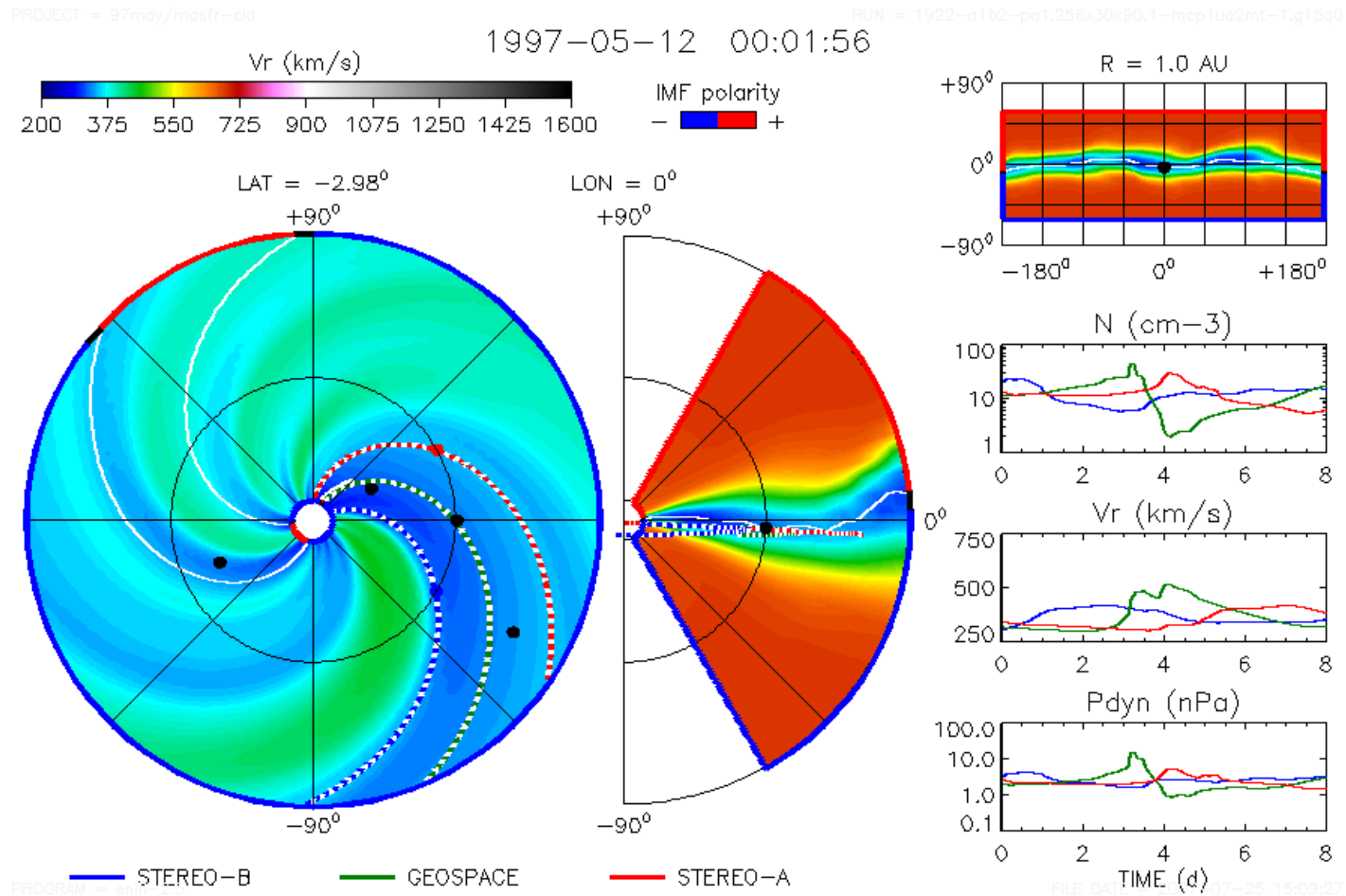
Gradual SEP events provide the largest, longest, and spectrally hardest events so our initial modeling efforts are focused on this type.



Stereo-B sees ICME and 'gradual' SEPs from its leading shock



# We assume the particle trajectories are the observer-connected field lines from the WSA-ENLIL heliospheric model with a cone model-initiated CME



(Cone model example from D. Odstrcil)

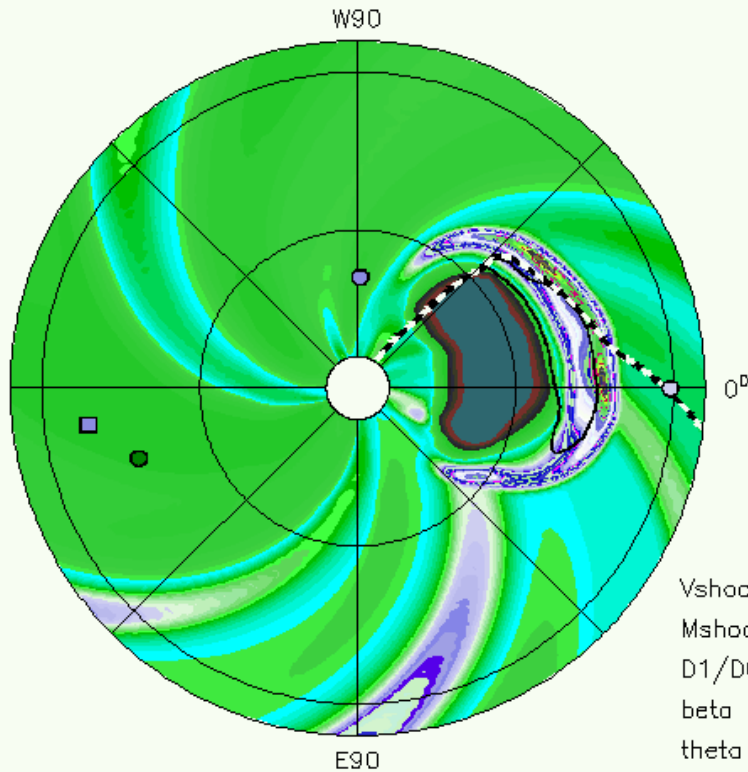
# An automated Shock Identification Scheme for ENLIL provides the needed shock parameters

ENLIL-2.6 medres WSA-1.6 GONG

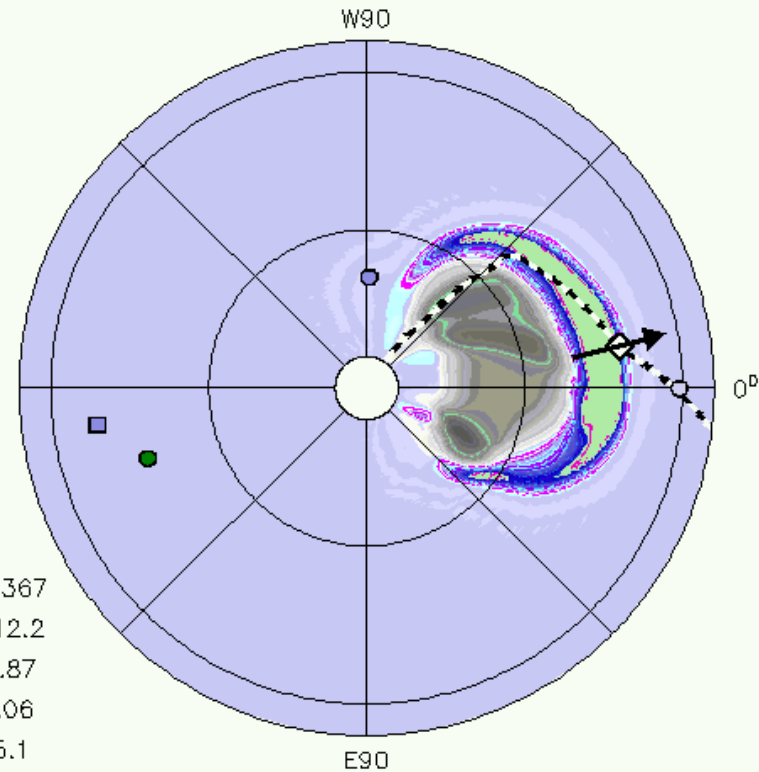
TIME = 27.02 h

2006-12-09 +1.12 days

● Mercury ● Venus ○ Earth ○ Mars ■ Messenger □ Stereo\_A ■ Stereo\_B



$V_{shock}=1367$   
 $M_{shock}=12.2$   
 $D1/D0=4.87$   
 $\beta = 0.06$   
 $\theta = 15.1$



$R^2*N - R^2*N_{amb} (cm^{-3})$   
 -20 10 0 10 20

3D IMF line  
 Shock normal X IMF line

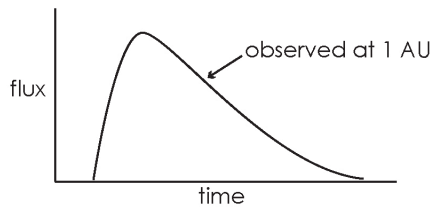
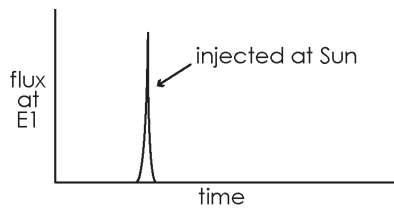
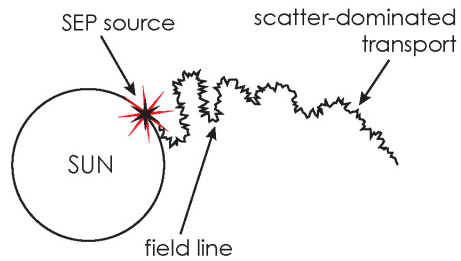
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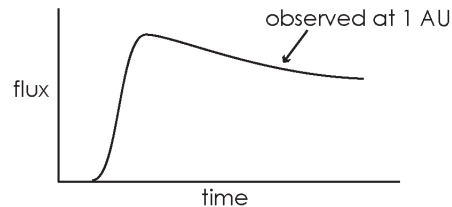
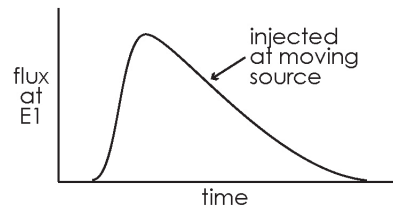
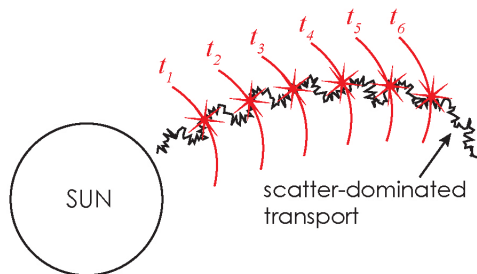
Scheme uses differencing between unperturbed and perturbed models to find and characterize the shock global structure

# SEP Transport Viewpoints

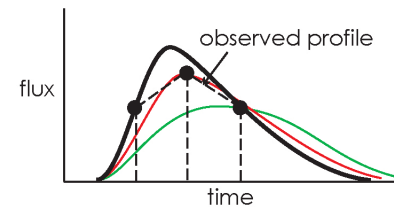
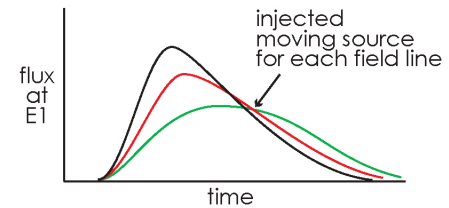
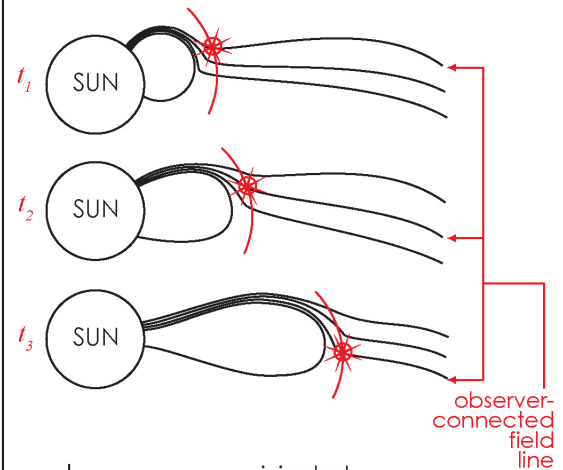
1) Diffusive Transport, solar source



2) Diffusive transport, moving, evolving source

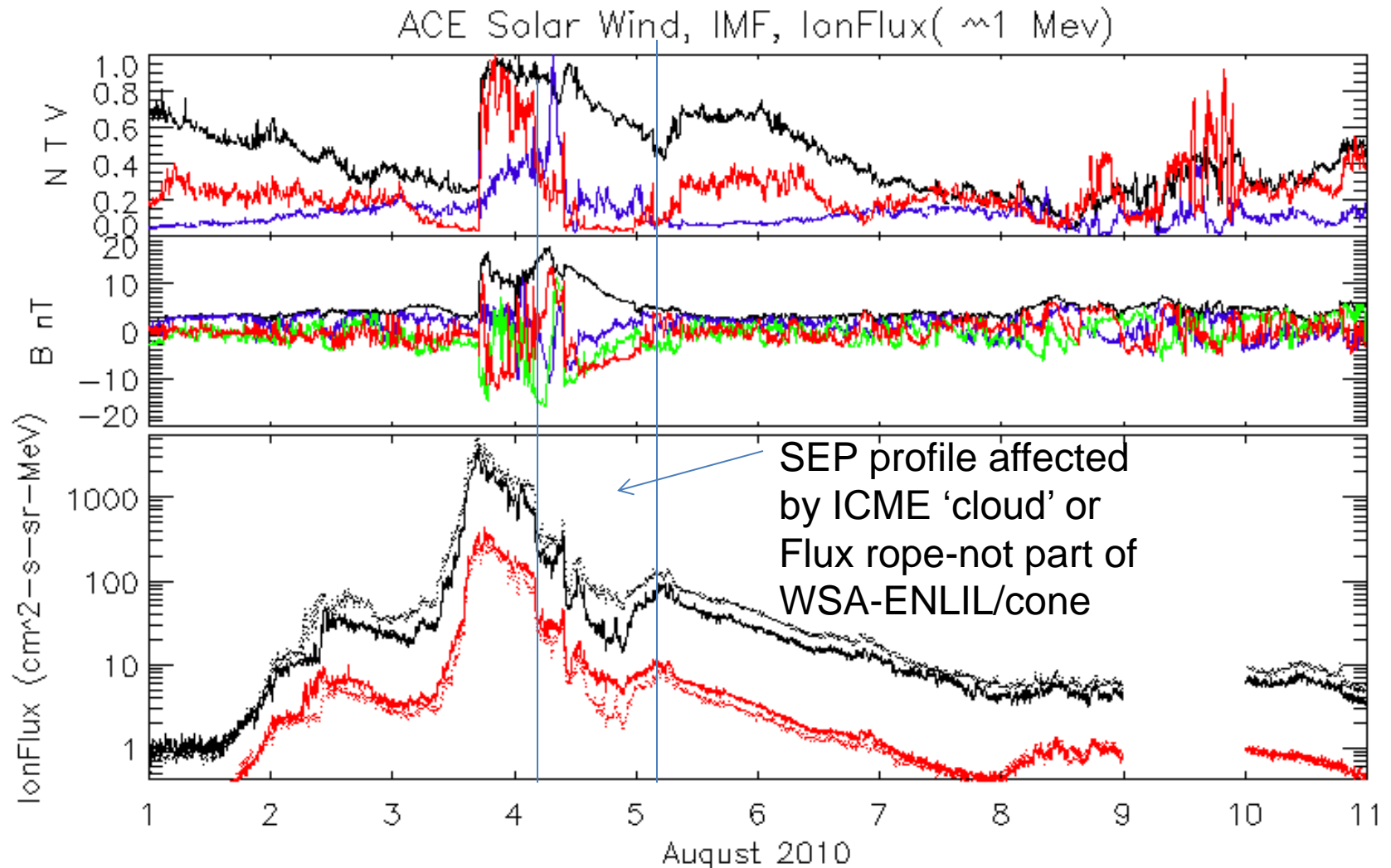


3) "Scatter-Free" transport, moving, evolving source (source may involve local scattering) \*



CISM Model view

# Example: Large, gradual SEP event seen by ACE in August 2010



Note that with the current background model, we cannot reproduce CME 'ejecta' effects on the SEP event time profile.

Notice that for this period, the Earth observer connection point migrates from one CME shock to another with time

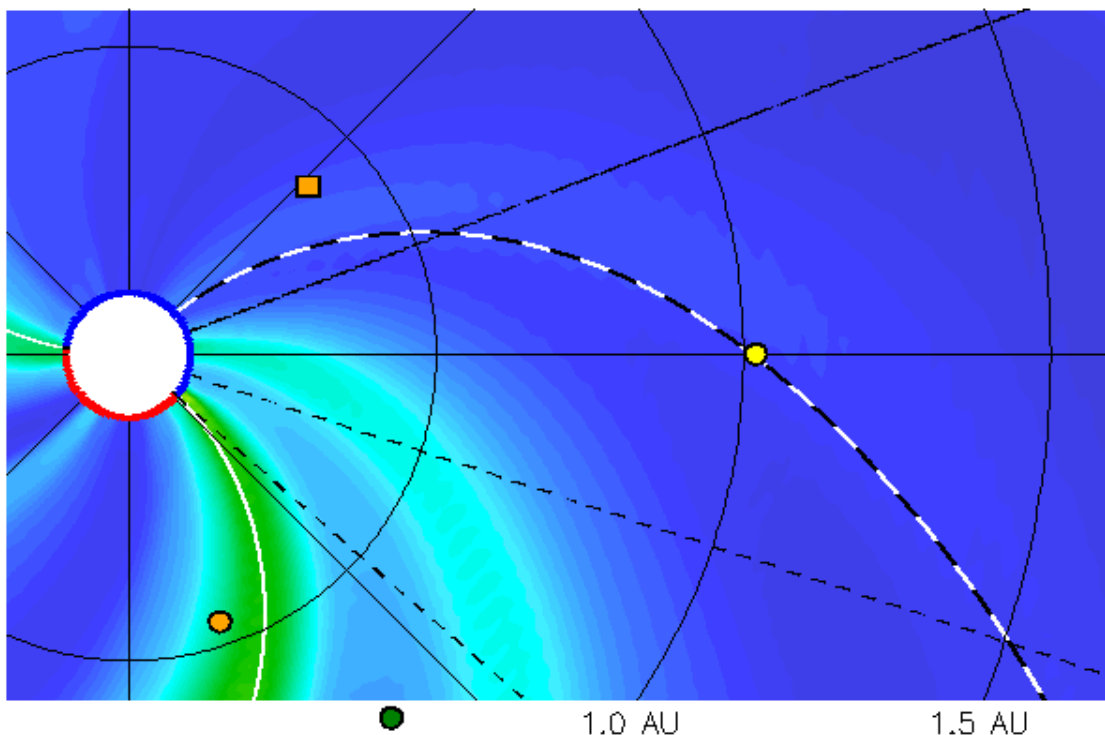
2010-08-01T00:00

Mercury  
Messenger

Venus  
Stereo\_A

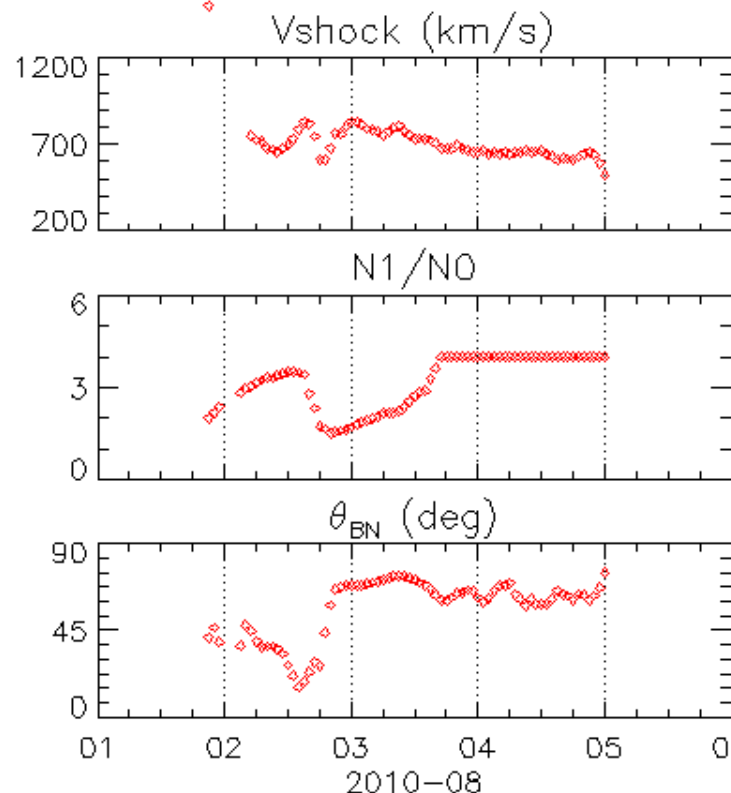
Earth  
Stereo\_B

Constant Latitude Plane



2010-08-01T00 +0.00 day

Mars



$R^2 N$  ( $\text{cm}^{-3}$ ) 0 5 10 15 20 25 30 35 40

IMF polarity - +

Current sheath

3D IMF line

ICME direct

ICME ejecta

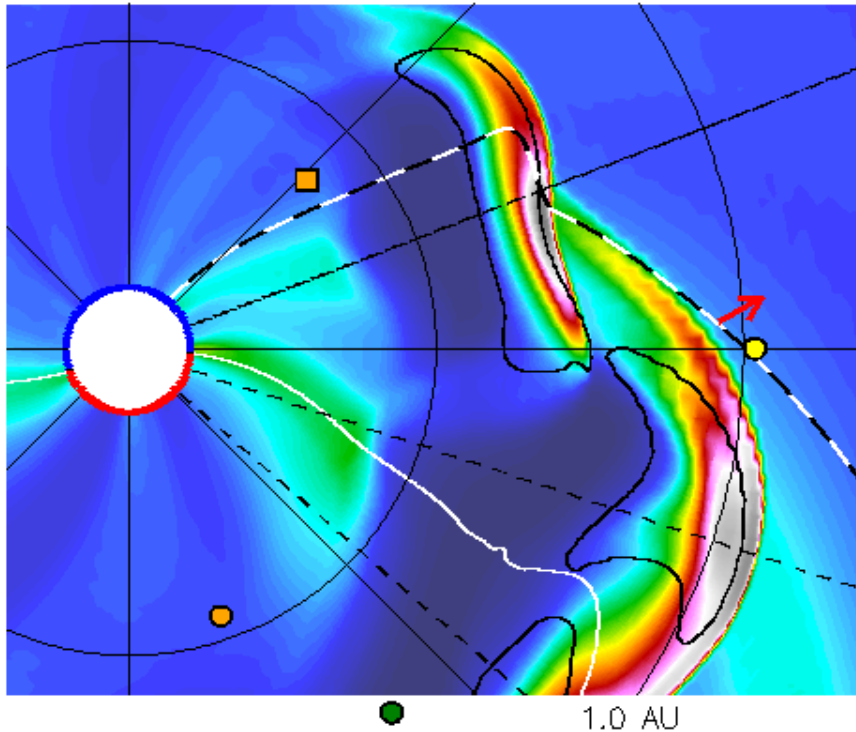
SEP event model uses both the field lines and the shock history.

# The SEP event at Earth reflects the connected shock and field line properties (ACE EPAM protons).

2010-08-03T12:00

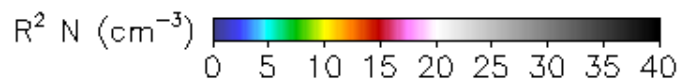
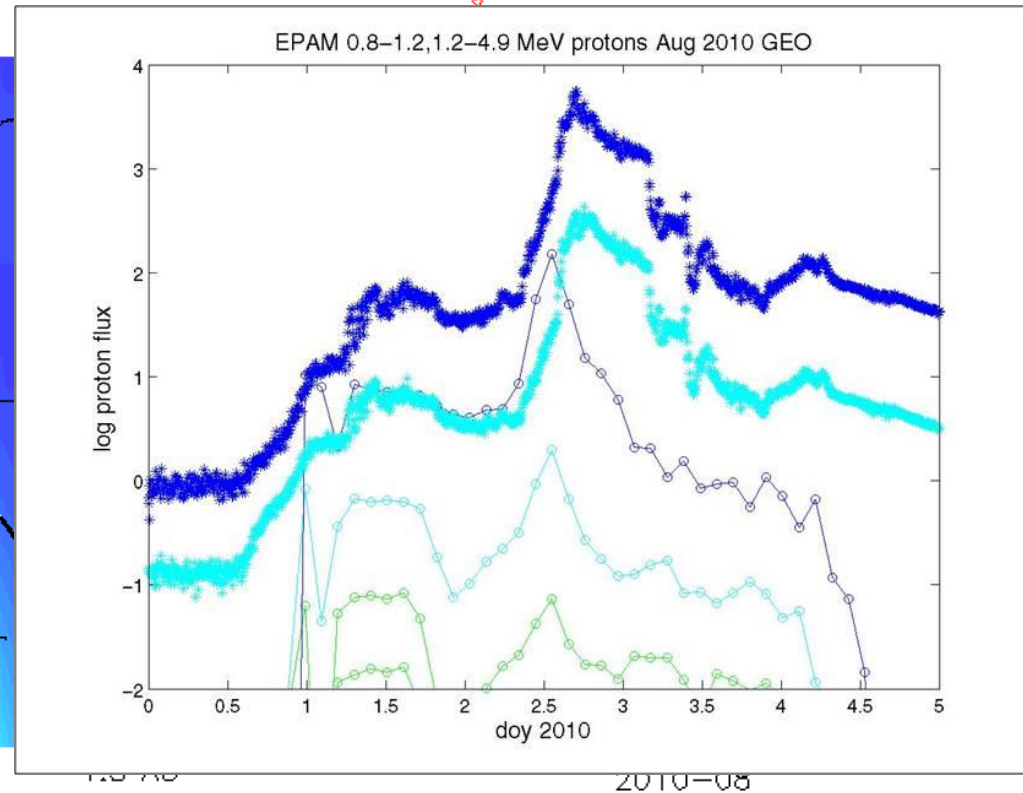
- Mercury
- Messenger
- Venus
- Stereo\_A

Constant Latitude Plane



2010-08-01T00 +2.50 days

- Earth
- Stereo\_B
- Mars



IMF polarity  
- [blue/red] +

Current sheath  
[grey bar]

3D IMF line  
[dashed line]

ICME direct  
[dotted line]

ICME ejecta  
[solid line]

# WSA-ENLIL/ cone parameters shock from the STEREO-B field line connection history are different

2010-08-01T00:00

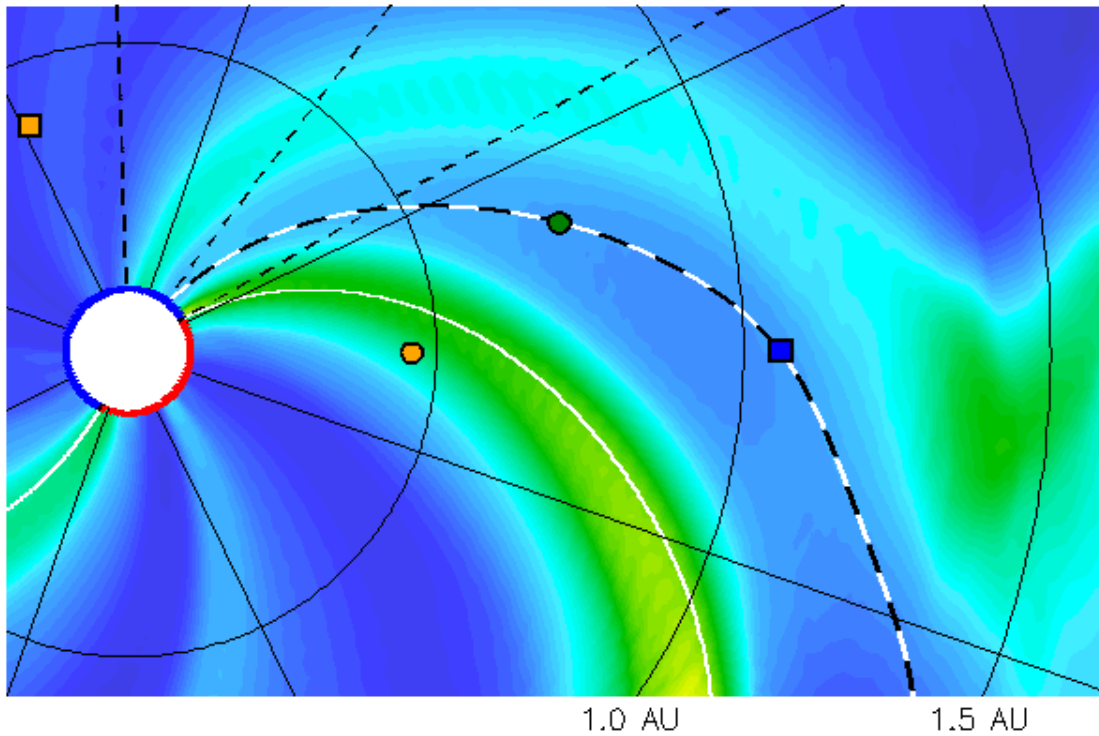
● Mercury  
■ Messenger

● Venus  
■ Stereo\_A

● Earth  
■ Stereo\_B

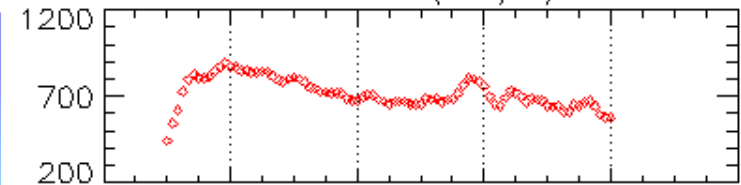
● Mars

Constant Latitude Plane

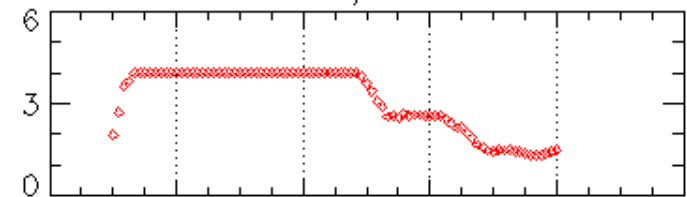


2010-08-01T00 +0.00 day

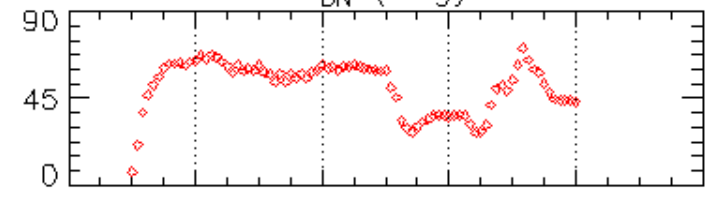
V<sub>shock</sub> (km/s)



N1/N0



$\theta_{BN}$  (deg)



2010-08

$R^2 N$  ( $\text{cm}^{-3}$ )

IMF polarity  
- +

● Current sheath  
—

3D IMF line  
—

ICME direct  
—

ICME ejecta  
—

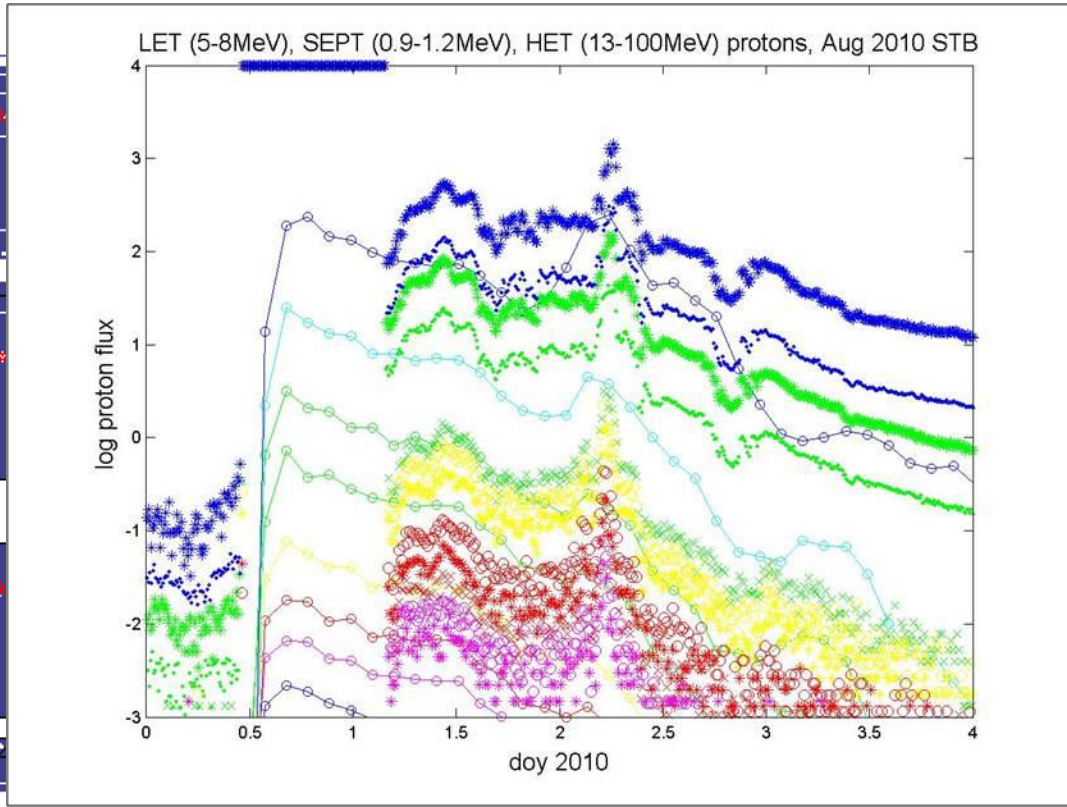
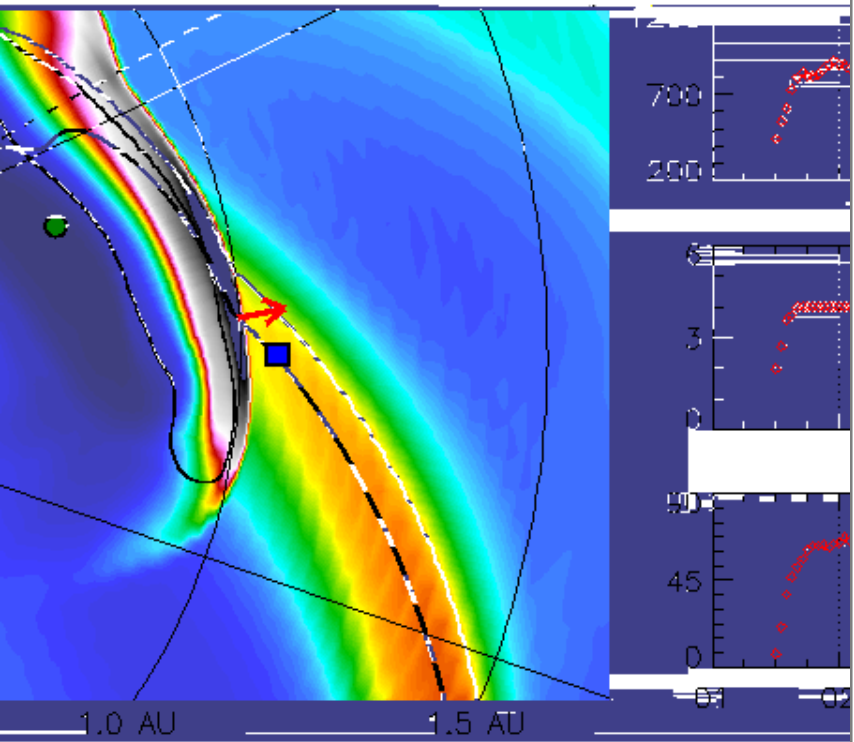
# The different field lines and shocks connecting to STEREO-B Make a much different SEP event (IMPACT LET, SEPT, HET data)

2010-08-03T07:00

2010-08-01T00 +2.29 days

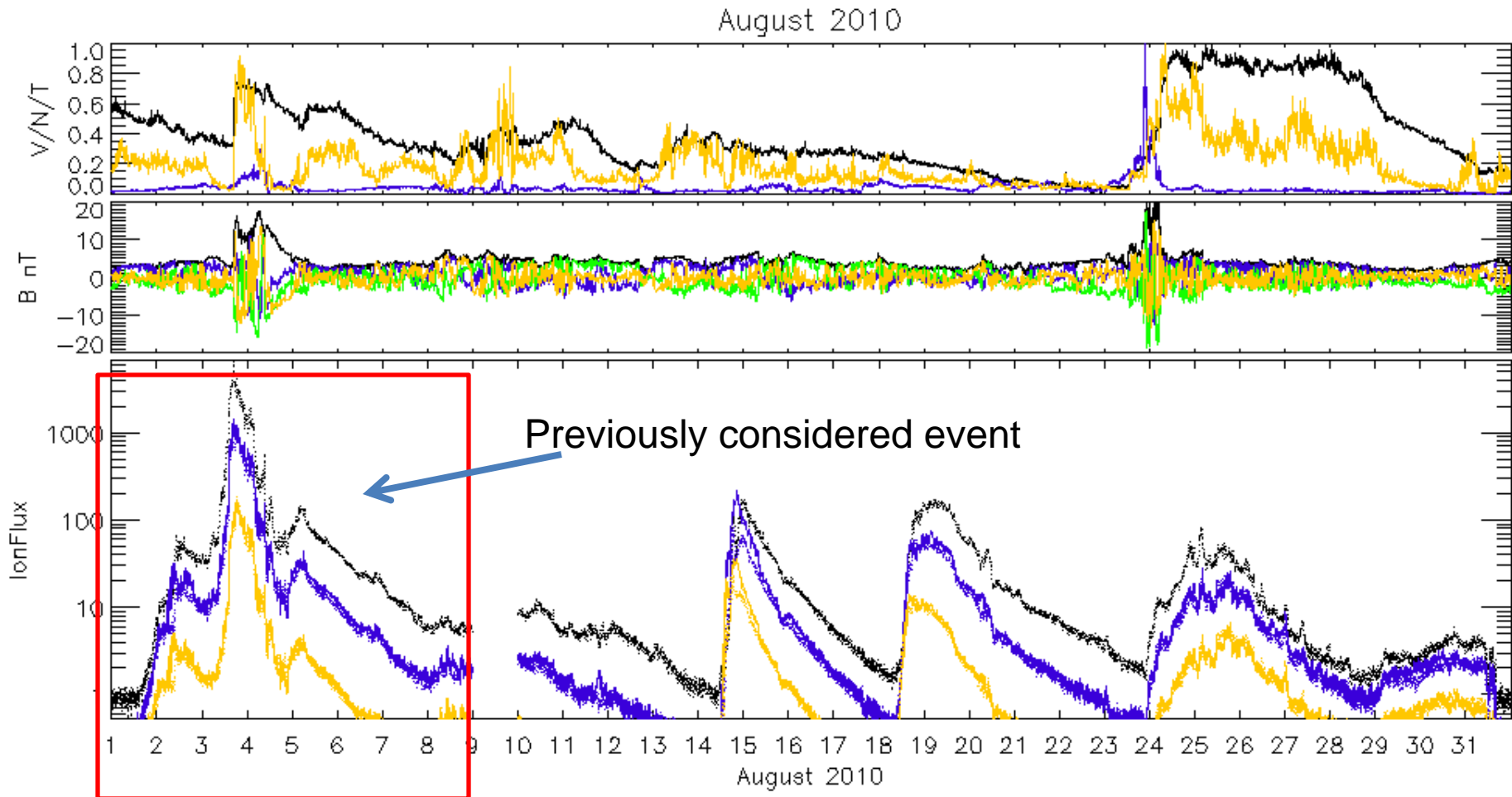
- Mercury
- Venus
- Earth
- Mars
- Messenger
- Stereo\_A
- Stereo\_B

Constant Latitude Plane





# ACE observations for all of August 2010



As solar activity increases SEP events, like CMEs, become less isolated. Challenge: 'rolling' models

# First step: numerically simulate the whole month of August 2010 using the ENLIL/cone CME model

2010-08-01T00:00

● Mercury  
■ Messenger

● Venus  
■ Stereo\_A

● Earth  
■ Stereo\_B

● Mars

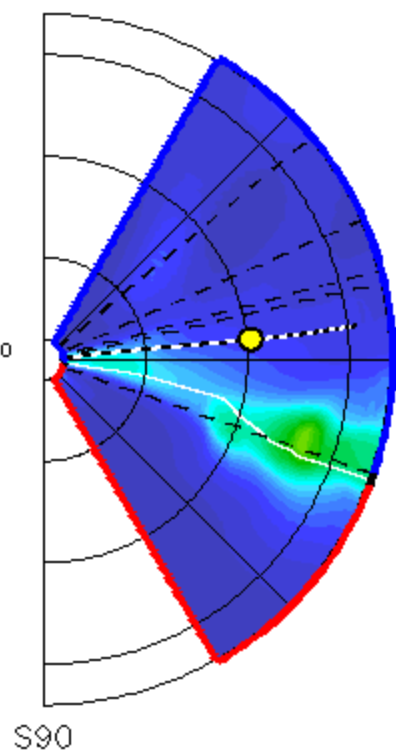
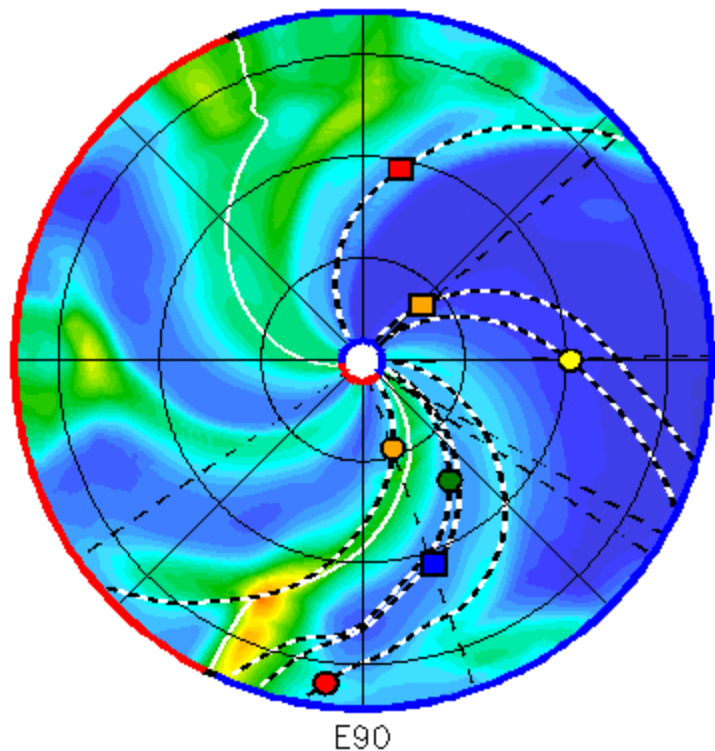
Const Lat Plane

W90

LAT = 5.75°

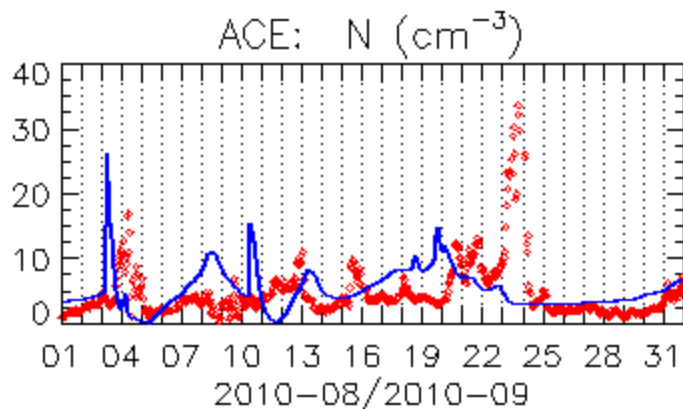
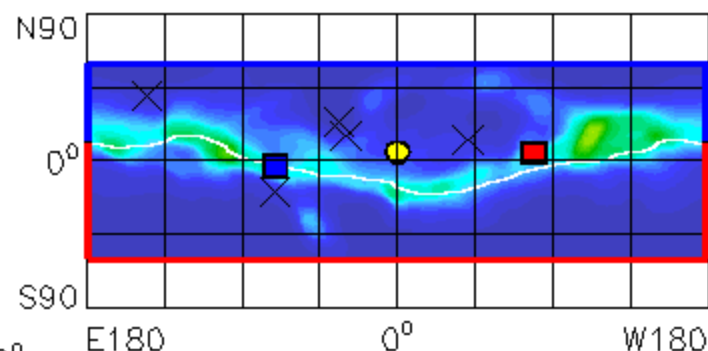
N90

LON = 0°



2010-08-01T00 +0.00 days

R = 1.0 AU



$R^2 N$  ( $\text{cm}^{-3}$ ) 0 10 20 30 40 50 60

IMF polarity - +

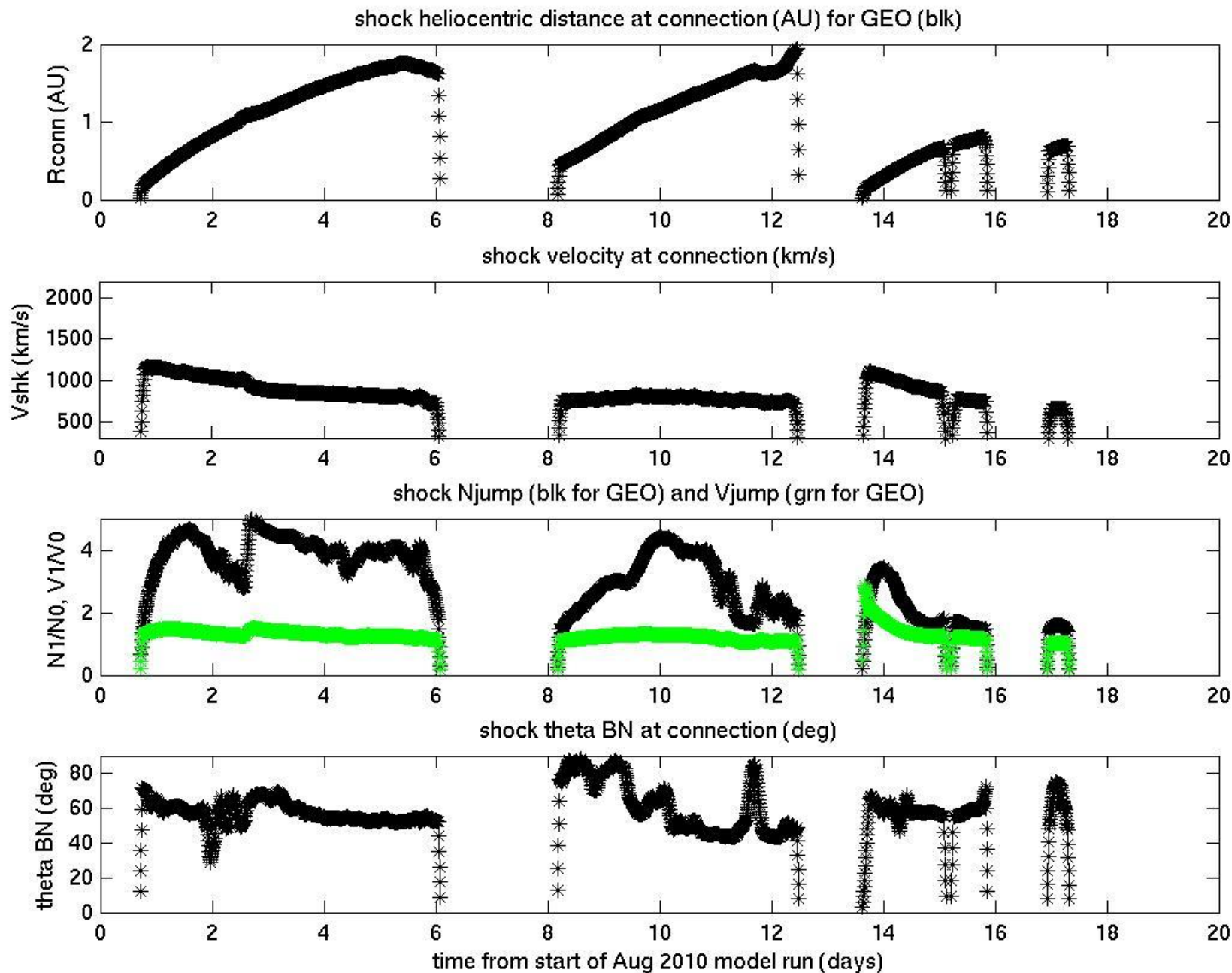
Current sheath

3D IMF line

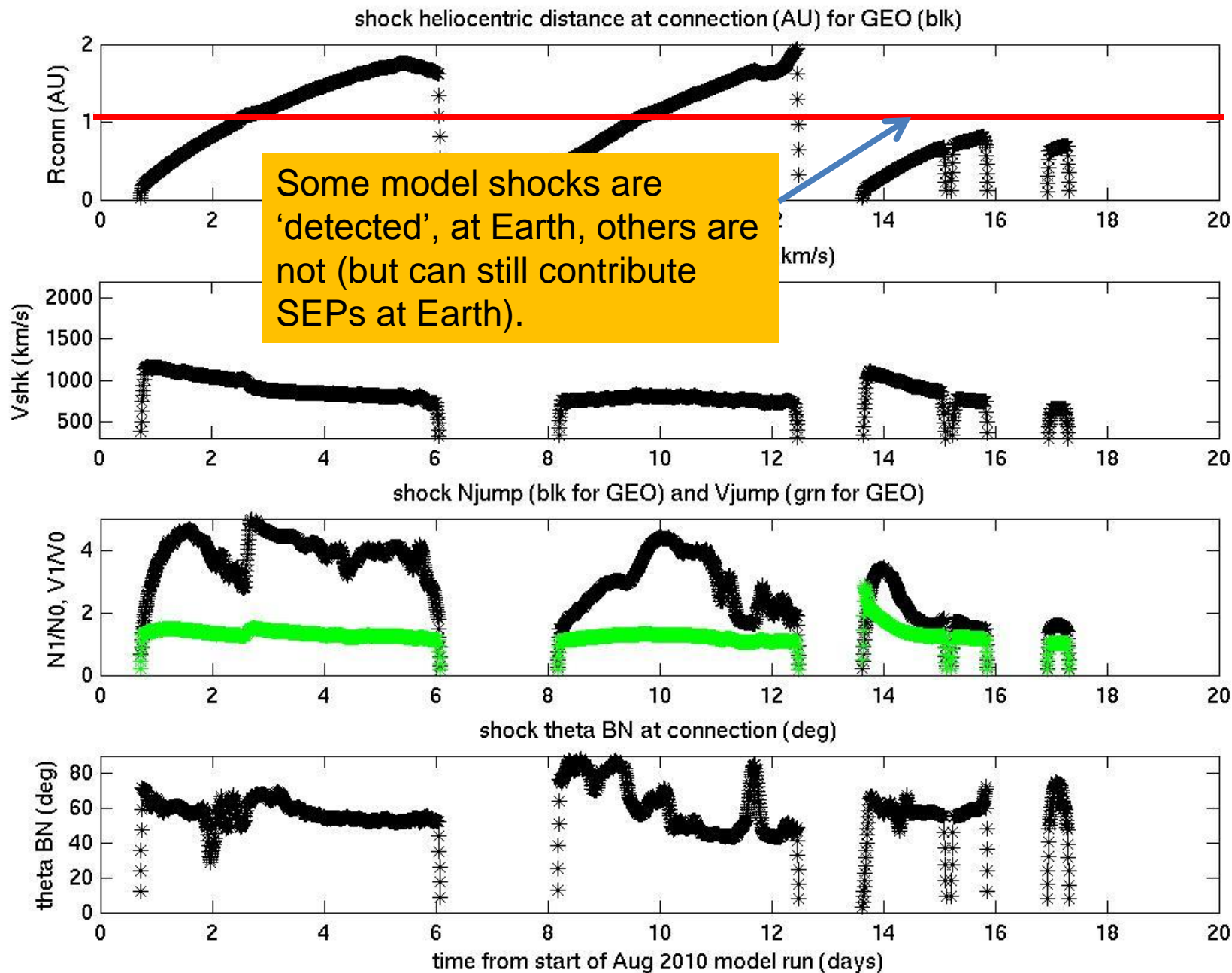
ICME direct

ICME ejecta

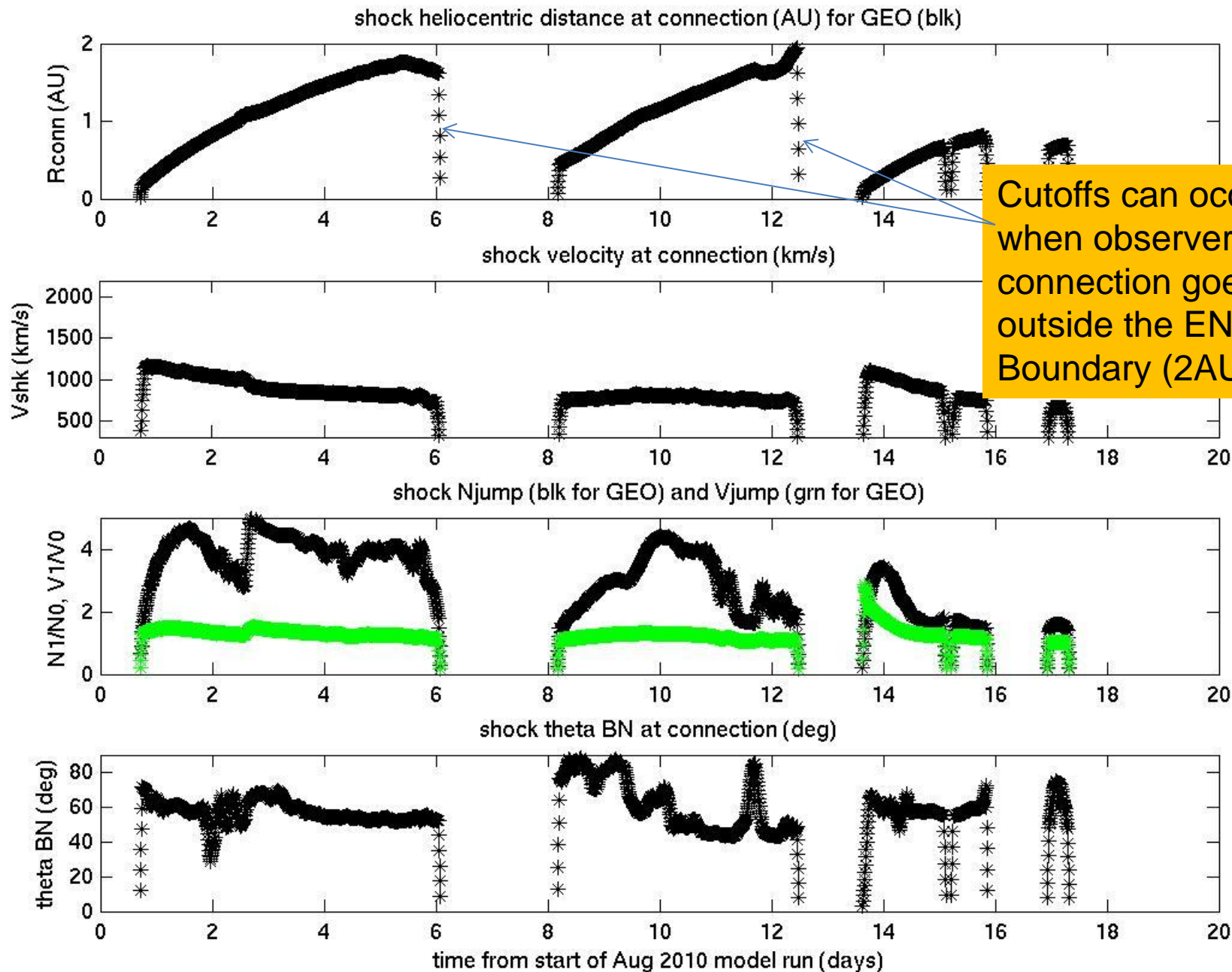
# All-August Summary of modeled observer-connected shock parameters for Earth



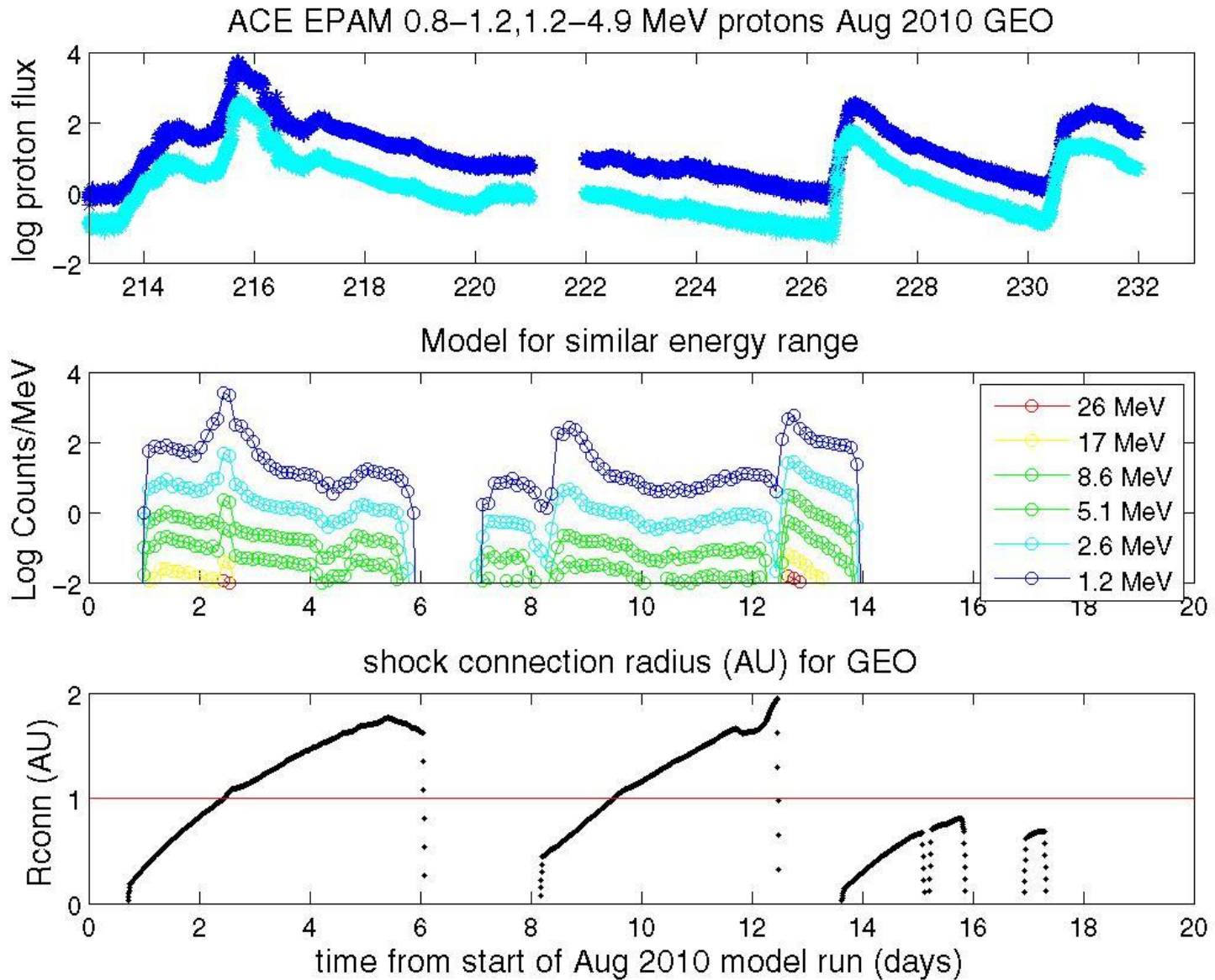
# All-August Summary of modeled observer-connected shock parameters for Earth



# All-August Summary of modeled observer-connected shock parameters for Earth



Allows rolling month-long runs of local SEP activity (top=data, middle=model)



## Bottom Lines + Lessons learned thus far:

\**Any* SEP event model will only be as good as the CME and heliospheric model it is based on.

\*SEP events may or may not be accompanied by the geomagnetic storm-causing shock or the shock and coronal ejecta. This impacts their predicted geoeffects.

\*The most extreme events (e.g.. GLEs) require modeling of the coronal portion of the shock (currently not part of WSA-ENLIL/cone).

\*Improvements can be made *now* based on applications performance, and someday by the same SEP event model that uses more complete background simulations (with corona and CME ejecta material and fields).

\*STEREO and ACE multipoint observations provide a particularly useful test because comparisons of the same solar event can be made at different locations

\*It's now time to routinely apply SEP event models tied to the routine WSA-ENLIL heliospheric models as the first step to this highly desired product.

# A Three-Stage Implementation Approach?

## *1. A Nearly Painless First Step interim product:*

Procure and install WSA-ENLIL/cone model with shock finder enhancements to track Earth-shock connections in existing routine runs

## 2. Second Step:

Allocate disk space for observer shock-connected field lines from simulation and plot for visual evaluation of its usefulness as a by-product

## 3. Third Step:

Add SEP source description and particle transport code.